ON THE JETS ASSOCIATED WITH GALACTIC SUPERLUMINAL SOURCES

Amir Levinson and Roger Blandford

Theoretical Astrophysics 130-33, Caltech, Pasadena CA 91125.

Abstract

Recent observations of GRS 1915+105 and GRO J1655+40 reveal superluminal motions in Galactic sources. This letter examines the physical conditions within these Galactic sources, their interaction with their environment, their possible formation, and contrasts them with their extragalactic counterparts. In particular, e^+-e^- and e-p jets are contrasted, constraints on particle acceleration in the jets are imposed using X-ray and radio observations, the γ-ray flux from e^+-e^- jets expected at EGRET energies and the flux in infrared lines from an e-p jet are estimated. It is also suggested that these sources may exhibit low frequency radio lobes extending up to several hundred parsecs in size, strong, soft X-ray absorption during the birth of the radio components and emission line strengths anti-correlated with the X-ray flux. The implications for other X-ray transients are briefly discussed.

1. Introduction

There is now direct evidence for superluminal motion in the radio images for two strong Galactic X-ray transient sources, GRS 1915+105 and GRO J1655+40 (Mirabel & Rodriguez 1994, hereafter MR94; Tingay et al. 1995; Hjellming & Rupen 1995, hereafter HR95). These motions are probably associated with relativistic jets emanating from a black hole in a X-ray binary. Several other transient radio sources associated with soft X-ray novae may also involve collimated jets (HR95). In this letter we use existing radio, optical and X-ray observations to place constraints on the physical conditions within these radio-emitting X-ray transients, contrasting them with their extragalactic counterparts. We first analyze the jets in some generality and then speculate upon how they may be collimated. We then illustrate these ideas using the two known examples and finally list possible observations that may further elucidate the natures of these sources.

2. Relativistic Jets

2.1 Synchrotron emission

The radio emission is observed to originate in pairs of radio components that move away from the central source with mildly relativistic speed. The particle acceleration and magnetic field amplification responsible for the synchrotron emission

may both be caused by internal shocks propagating along a jet. Consider one such jet formed at $r \equiv 10^x r_x$ cm $\sim 10^6$ cm near a black hole in a X-ray binary of orbital radius $a \sim 10^{12}$ cm, that propagate out into interstellar space $r \lesssim 10^{20}$ cm with an opening angle $\phi(r)$. Relativistic electrons accelerated *in situ* should radiate by the synchrotron and inverse Compton processes and the former should dominate at large radius. From the resolved radio images, it is possible to estimate a fiducial equipartition field strength B^*, in the normal manner using the time-averaged radio intensity and assuming (falsely) that the source is stationary. (Numerically, $B^* \sim 4(T_{B6}/\phi_{-1}r_{16})^{2/7}\nu_9^{5/7}$ mG, where the brightness temperature $T_B = 10^6 T_{B6}$ K is evaluated at the frequency $\nu = \nu_9$ GHz assuming that the radio spectral index $\alpha_R \sim 0.5$, e.g., Rybicki & Lightman 1979.)

If the jet Lorentz factor is Γ and its velocity makes an angle θ with the line of sight, we can define an observer's Doppler factor $\delta_o = [\Gamma(1-\beta\cos\theta)]^{-1}$. As the synchrotron cooling time is long compared with the dynamical time, the jet power associated with the emitting electrons and the electromagnetic field satisfies

$$L_{je} \gtrsim \frac{c}{2}\left(\frac{\Gamma B^* \phi r}{\delta_o^{5/7}}\right)^2 \sim 10^{34}\Gamma^2\delta_o^{-10/7}(B^*_{-3})^2\phi_{-1}^2 r_{16}^2 \mathrm{ergs}^{-1} \qquad (1)$$

where rough equality occurs at equipartition and the jet power rises $\propto (P_{mag}/P_e)^{-3/4}$ if the jet is particle-dominated and $\propto (P_{mag}/P_e)$, if it is magnetically-dominated.

The inertia of the surrounding gas will decelerate the head of the jet. The speed of advance of the head V_h can be estimated by equating the ram pressure of the surrounding material measured in a frame comoving with the head, with the jet thrust (e.g, Begelman et al. 1984). As long as V_h is supersonic, strong shocks may be formed at the outer lobes, as in extragalactic FRII sources, and can give rise to enhanced, steep spectrum synchrotron emission that can be seen at low radio frequencies as hot spots. If V_h is subsonic, then low frequency radio observations may reveal a source similar to FRI objects.

To estimate the maximum radio power emitted by the lobes, we assume that the lobes subtend ~ 1 steradian so that their pressure is $\sim L_j^{2/3}\rho^{1/3}r^{-4/3} \sim 3 \times 10^{-7} L_{j38}^{2/3} n^{1/3} r_{18}^{-4/3}$ dyne cm^{-2}. (In contrast to the powerful extragalactic sources, radiation loss is unlikely to be important in the hot spots.) The lobe brightness temperature at a fiducial frequency ~ 5 GHz then satisfies

$$T_{B5} \lesssim 4 \times 10^5 L_{j38}^{7/6} n^{1/2} r_{18}^{-4/3} \quad \mathrm{K} \qquad (2)$$

where equality requires equipartition. If the source is too young or particle acceleration is too inefficient, the brightness temperature will be much less than the upper limit. Otherwise, these lobes should be detectable against the normal Galactic radio backgound. If there is a small population of ultrarelativistic Galactic jets then it is possible that none of them will be beamed towards us and that we can only detect their presence from their double radio lobes.

2.2 Inverse Compton scattering

Accelerated relativistic electrons can also radiate by inverse Compton scattering of accretion disk radiation. Let the energy density be dominated by photons of energy $E_X \sim 1$ keV (in contrast to ~ 10 eV for extragalactic sources) and luminosity $L_s(r)$ and let the characteristic Doppler factor for transforming this radiation into the frame of the jet be $\delta_j(r)$ so that the associated photon energy in the jet frame is $E'_X \sim \delta_j E_X$. Introduce a characteristic electron cooling energy in the jet frame by equating the radiative cooling time to the outflow timescale

$$E'_{ec}(r) \sim 3 \left(\frac{\Gamma}{\beta k_j}\right) L_{s38}^{-1} r_{12} \mathrm{GeV}, \tag{3}$$

where $k_j \sim< \delta_j^2 >\sim \Gamma^2 r_7^{-4}$ for direct illumination by the accretion disk and $k_j \sim \Gamma^2 \tau$, if this radiation is scattered locally by free electrons in the surrounding medium with local Thomson depth τ. Inverting Eq. (3), we can define a cooling radius $r_c(E'_e)$, within which electrons of energy E'_e will cool. In order to accelerate an electron to an energy $\gtrsim E'_{ec}$ requires that the particle acceleration occur impulsively on a timescale $t'_{acc} < r/\Gamma c$. The maximum γ-ray energy that can be scattered is then $\delta_o(r/\Gamma c t'_{acc})E'_{ec}$. The scattered flux and spectrum depend upon the fraction of the jet kinetic energy that is transformed into relativistic particles in this manner. If a fraction η of the jet power is emitted as γ-rays, the integrated γ-ray flux at Earth will be,

$$F_\gamma \sim 10^{-8} \eta \delta_o^2 L_{j38} D_4^{-2} \mathrm{ergs\ s^{-1}\ cm^{-2}} \tag{4}$$

where D_4 is the distance to the source in 10^4 pc. Further features of the Compton scattering depend upon whether the jet is pair - or proton - dominated.

2.3 $e^\pm$ jet

If γ-rays are emitted at small enough radius, they will not be able to escape without creating electron-positron pairs. These, in turn, can produce lower energy γ-rays and a cascade will develop which terminates when the γ-ray has a low enough energy to escape. The region from which γ-rays of a given energy can escape is known as the γ-*sphere* and its radius is

$$r_\gamma(E_\gamma) \simeq 3 \times 10^7 k_{pp} L_{E44} (m_e^2 c^4 / E_\gamma) \quad \mathrm{cm}, \tag{5}$$

where $10^{44} L_{E44}$ s^{-1} is the spectral luminosity of the central X-ray source, $k_{pp} \sim< 1 - \cos\phi >$ for radiation from an accretion disk that propagates at an angle ϕ to the jet and $k_{pp} \sim \tau$ if the local scattered component dominates (c.f., Blandford & Levinson 1995). We can invert Eq. (5) to define the the threshold energy $E_{\gamma th}(r)$ which is the maximum energy of an escaping γ-ray from radius r.

Now, pairs will cool to subrelativistic energies for $r \lesssim r_c(m_e c^2) \sim 3 \times 10^8 k_j L_{s38}$ Γ^{-1} cm. Their density will be limited by annihilation (Blandford & Levinson 1995). We can also define an *annihilation radius*, within which the density of annihilated pairs becomes smaller than that required to carry the jet power. Consequently, pair jets require the presence of some other carrier of energy and momentum. In the

absence of baryons this is presumably electromagnetic. For subrelativistic pairs, $r_{ann} \sim 3 \times 10^9 L_{j38} \Gamma^{-1}$ cm, and is somewhat less if the pairs remain relativistic.

Another important difference between the Galactic and the extragalactic sources is that the former have much steeper X-ray spectra and consequently their γ-spheric radii increase more rapidly with increasing γ-ray energy. Furthermore, $E_{th}(r_{ann}) \sim 1$ GeV, instead of ~ 1 MeV as in the extragalactic case. This probably means that the γ-ray spectrum will be flatter in the MeV-GeV range. Furthermore, the bulk Lorentz factors of the jets in the bright EGRET AGN sources are typically of order 10, much larger than those inferred for the jets in the Galactic sources.

A plausible picture of Galactic $e^{\pm}$ jets, based on the above results, is as follows: some fraction of the accretion luminosity (or the spin energy of a rotating black hole) is extracted from the central source in the form of a collimated electromagnetic jet. During quiescent states, the jet is essentially invisible. However, when either the particle acceleration is sufficiently rapid or a reduced ambient radiation field renders the inverse Compton radiation loss sufficiently ineffective, pairs can be injected to energies above $E_{th}(r)$ and an intense pair cascade is initiated. At this radius a transition to a particle dominated flow occurs via the evolution of the cascade, leading to γ-ray emission and the eventual formation of a superluminal radio feature. If the cascade is initiated within the annihilation radius, the mildly relativistic pairs will be annihilated and the radio spectrum will exhibit a low energy cutoff.

2.4 e-p jet

If the jet is accelerated and collimated close to the black hole as an e-p plasma, perhaps through the agency of radiation pressure, and particle acceleration is inefficient above $\gtrsim E_{\gamma th}(r)/\Gamma$, then pairs are not created and the minimum jet power is larger than that given by Eq. (1) by a factor $\sim [m_p/\gamma_{min} \ln(\gamma_{max}/\gamma_{min}) m_e]^{4/7}$, where the electron distribution function is supposed to extend from γ_{min} to γ_{max}. Typically, this factor is $\sim 3 - 30$. (Alternatively, a pair jet may form as described above and plasma from the surrounding wind may be entrained.)

One possible diagnostic of e-p jets is the presence of Doppler-shifted spectral lines, such as H_α, as seen in SS433. Due to the relativistic motion of the jet the line will be Doppler shifted by the approaching and receding Doppler factors δ_o. Following Begelman et al. (1980) and Davidson & McCray (1980), we suppose that the gas in the line-emitting region is clumped, and denote by ε the volume filling factor of the dense blobs comprising the line-emitting beam and by $10^{15} R_{15}$ cm the beam's length. The H_α emissivity should lie in the range between $10^{-24.6}$ and 10^{-23} ergs cm^3 s^{-1} at $\sim 10^4$ K (Davidson & McCray 1980), depending on the density in the emitting blobs. Let us adopt the value $10^{-23.5}$ ergs cm^3 s^{-1}. We then obtain for the emitted flux

$$F_{H_\alpha} \simeq 10^{-23} \delta^2 \left(\frac{L_{j38}}{D_4} \right)^2 (\varepsilon R_{15} \phi^2 \Gamma^4)^{-1} \ \text{ergs cm}^{-2} \text{ s}^{-1}, \qquad (6)$$

where it has been assumed that the average density of the hot phase is $\varepsilon n_{\rm cold}$. The cold blobs should be confined by the pressure of the hot phase in the jet or, alternatively, by the magnetic fields.

3. Jet Formation and Confinement

The Galactic superluminal sources further demonstrate that relativistic jet formation can operate on a stellar as well as a galactic scale. Presumably, the common feature is the presence of an accretion disk orbitting in a relativistically deep potential well. In order to explore how this might occur in a ($M \sim 3 - 10$ $M_\odot$) binary X-ray source, we suppose that the jet is collimated by a wind emanating from the disk surface over a range of radii from $\lesssim 10^7$ to $\gtrsim 10^{11}$ cm with speed. $V_W = 1000 V_{W8}$ km s^{-1} declining with cylindrical radius. As the jet propagates away from its source, there will be radial transport of linear momentum which will flatten the velocity profile. If most of the momentum derives from large disk radius, then the asymptotic jet speed will be $V_{W8} \sim 1 - 10$.

It has long been argued in the case of AGN and protostellar jets, that a hydromagnetic wind is a more plausible collimator than a purely hydrodynamic wind because when the field is primarily toroidal, the transverse force density is $-r_\perp^{-2} d(r_\perp^2 P_{mag})/dr_\perp$ (as opposed to $-dP_{gas}/dr_\perp$ for gas pressure) allowing a smaller magnetic pressure to focus a jet of larger total pressure. In addition, P_{mag} declines less rapidly than P_{gas} as the wind expands which implies that magnetic collimation is likely to become relatively more important. We adopt the magnetic collimation hypothesis, though much of what follows is more general.

For $r << a$, magnetic confinement of the jet can be relatively effective with each nested magnetic surface confining the interior flow, until ultimately the inertia of the wind from the outer disk prevents transverse expansion. However, this magnetic focusing cannot provide much pressure amplification after the jet has propagated out to a radius comparable with the outer radius of the disk. At this point, either the jet itself must have sufficient internal density to be effectively free and travel hypersonically with Mach number $\gtrsim \phi^{-1}$ or it must be confined by the inertia of the surrounding wind. The former possiblity may be relevant for e-p jets. However, we suspect that pair jets require external confinement at this radius. The forgoing considerations suggest that the jet itself exerts a transverse pressure of

$$P \sim 3 \times 10^4 L_{j38} \Gamma^{-2} \beta^{-1} r_{12}^{-2} \phi_{-1}^{-2} \mathrm{dyne cm}^{-2} \qquad (7)$$

which will cause the surrounding, slower wind to expand with a speed $\sim (P/\rho_{Wj})^{1/2}$ $\lesssim V_{Wj}\phi$, where Wj denotes values of the wind density and speed averaged within a few jet widths. The *minimum* wind discharge for ultimate inertial confinement at radius $r \sim a$ is then given by

$$\dot{M}_{Wj} \gtrsim 10^{-4} L_{j38} \Gamma^{-2} \beta^{-1} \phi_{-1}^{-2} V_{Wj8}^{-1} \mathrm{M}_\odot \mathrm{yr}^{-1} \qquad (8)$$

and the associated wind power is $\gtrsim 10^{38} L_{j38} \Gamma^{-2} \beta^{-1} \phi_{-1}^{-2} V_{Wj8}$ erg s^{-1}. (In making this estimate we have supposed that most of the discharge is confined to a polar wind with transverse scale ~ 3 jet radii. If the wind fills a larger solid angle, the discharge and power must correspondingly be increased.) This wind will propagate well beyond the observed radio sources before terminating through a strong shock when its momentum flux balances the ambient interstellar pressure.

We can now use this simple prescription to estimate the physical conditions in the wind. If we measure the wind discharge as $\sim 10^{-6}\dot{M}_{Wj-6}$ $\mathrm{M}_\odot$ yr^{-1}, its Thomson optical depth is likely to be $\tau_T(r) \sim 0.1\dot{M}_{Wj-6}V_{W8}^{-1}r_{12}^{-1}\mathrm{M}_\odot$ yr^{-1}, for $r_{12} \gtrsim 0.1$. For $r_{12} \lesssim 0.1$, we emphasize that the optical depth need not be much greater than this value because of the efficacy of magnetic confinement. However, the wind that we postulate is likely to extinguish any soft X-ray flux if it is strong enough to collimate the jets.

This wind may also be observable optically. Its thermal state depends upon the photoionizing flux. The ionizing parameter is $U \sim 0.1L_{UV36}V_{W8}/\dot{M}_{Wj-6}$. For $0.1 \lesssim U \lesssim 10$, a two phase medium is possible with hot Compton-heated gas at a temperature $T \sim 10^7 - 10^8$ K coexisting with line-emitting gas at a temperature $T \sim 10^4$ K. (At the density envisaged, the thermal equilibration time turns out to be short compared with outflow time.) Now suppose that the mass accretion rate increases as a consequence of some disk instability. The ultraviolet and X-ray emission will increase as a consequence of enhanced dissipation at the inner disk. This in turn will heat the gas so that the pressure is largely thermal as opposed to largely magnetic. We propose that this prevents effective magnetic collimation and consequently a jet does not form. When the disk accretion rate falls, the ionization parameter falls and the gas in the wind cools so that it becomes magnetically dominated. This allows a collimating hydromagnetic wind to form. If there is also a central source of relativistic plasma or electromagnetic energy, perhaps derived from the spin of a central black hole, then this will form the radio-emitting core of the radio jet. This possibility is relevant to the observation that the radio outbursts appear to follow the X-ray outbursts in GRO 1655-40 (see below). A possible, alternative model for an accretion rate-radio jet connection has been proposed by Meier (1995). This wind is also likely to be a source of optical and ultraviolet emission lines and our model predicts that the fraction of the bolometric flux reprocessed in the form of emission lines should be anticorrelated with the X-ray flux.

4. Interpretation of GRS 1915+105, GRO J1655-40

4.1 GRS 1915+105

This source is at a distance of $D_4 \sim 1.25$ (MR94), and exhibits X-ray luminosity of a few times 10^{38} ergs s^{-1} (Harmon et al. 1994). It has been observed by the VLA at 5 and 10 GHz. Following MR94 we assume, for simplicity, that the pattern speed and the flow speed are equal (c.f., Bodo & Ghisellini 1995). The inferred speed and angle to the line of sight of the ejecta are then $\beta \sim 0.92$ and $\theta = 70 \pm 2^\circ$ (MR94), corresponding to $\delta_o \simeq 0.57$. (This measurement allows us to predict the wavelengths of, for example, possible H_α lines, namely ~ 1.15, 2.15 μ.) The radio features appear to move away at a constant speed out to a distance of at least 0.1 pc from the central source (MR94).

On March 24, 1994 the measured flux was ~ 0.7 Jy. Even though the source was not resolved at that time, the inferred distance from the putative core was

~0.08 arcsec, and the blob size was about 0.06 arcsec, corresponding to a linear size of $\sim 10^{16}$ cm. We estimate $P_{min} \simeq 1.8 \times 10^{-5}$ dyn cm^{-2}, and $B^* \simeq 2 \times 10^{-2}$ G, at a distance of $\sim 10^{16}$ cm from the central source. Eq. (1) then gives $L_{j38} \gtrsim 2$ for $e^{\pm}$ jet, and about 4 times that for $e-p$ jet. The annihilation radius $r_{ann} \gtrsim 2.4 \times 10^9$ cm. Taking $\kappa_{pp} L_{s38} = 10^{-2}$ yields $r_\gamma \simeq 2.5 \times 10^8 \left(E_\gamma/10^3\right)^{0.5}$ cm. Since $r_\gamma(1GeV) < r_{ann}$ low frequency cutoff of the radio spectrum from the jet may be expected. The acceleration time required for a formation of a particle loaded blob is $\lesssim 10^{-3}(r/c)$. From equation (4) it follows that $F_\gamma \gtrsim 3.5 \times 10^{-9}\eta$ ergs cm^{-2} s^{-1}. If the radiative efficiency $\gtrsim 0.1$, γ-ray outbursts from this source, if comprises of e$^{\pm}$ pairs, might be detectable. From equation (6) we obtain $F_{H_\alpha} \lesssim 10^{-14}$ ergs s^{-1} cm^{-2}.

4.2 GRO J1655-40

For this source we adopt the parameters inferred by HR95, namely $D_4 = 0.31$ (this distance is in a very good agreement with the distance inferred by Bailyn et al. 1995, based on interstellar absorption), $\beta = 0.92$, and $\delta_o \simeq 0.46$. (The predicted H_α wavelengths are $1.4, 1.8\mu$.) The lowest frequency observed with the VLA was $\nu_{10} = 0.15$. The light curves indicate a peak flux of 5.5 Jy at this frequency 6 days after the beginning of the observations, implying $l < 10^{16}$ cm, and $T_{B5} \sim 10^7$ K. During the high X-ray state Harmon et al. (1995) derived a 20-100 keV luminosity of about 10^{37} ergs s^{-1} and energy spectral index of -3.1. The spectrum appears to harden to -2.5 when the flux drops. If we extrapolate the spectrum down to 1 keV, we estimate $L_{s38} \lesssim 1$ during high states. However, the X-ray luminosity was in fact smaller during the peak of the radio flux, as discussed below. For illustration we shall assume $\kappa_{pp} L_{s38} = 10^{-3}$. Adopting these parameters we obtain, $P_{min} \simeq 5 \times 10^{-6}$ dyn cm^{-2}, $B^* \simeq 10^{-2}$ G, $L_{j38} > 0.6$, $r_{ann} > 7 \times 10^8$ cm, and $r_\gamma \sim 10^7 (E_\gamma/10^3)^{0.5}$ cm, for $e^{\pm}$ jet. For e-p jet $L_{j38} \gtrsim 3$. The H_α flux obtained from Eq. (6) is roughly the same as that obtained for GRS 1915

Bailyn & Orosz (1995) have measured a spectroscopic orbital period of 2.6 d and a mass function $f_1 = 3.35 \pm 0.14$ M$_\odot$ implying that the compact object is a black hole with a mass 5.3 M$_\odot$ and $a \sim 1 \times 10^{12}$ cm. They have also reported observations of a hard optical continuum with spectral index $d \ln F_\nu / d \ln \nu \sim 0.3$ (similar to that expected from a classic accretion disk) as well as an emission line spectrum exhibiting Balmer lines and HeI and a F/G stellar spectrum. The presence of eclipses verifies that the inclination $i \sim 90°$. After correcting for reddening the optical luminosity is ~ 0.01 times the X-ray power. The intensity is comparable with that expected from a wind of the strength that we have had to posit to account for the radio jet collimation with a filling factor of order unity and the line widths are compatible with those expected from a wind with $V_{W8} \sim 1$.

The radio outbursts observed seem (Tingay et al. 1995; Harmon et al. 1995) to follow the hard X-ray bursts with a lag of a few days to a few weeks; the radio flux rises as the X-ray flux falls. The flattening of the hard X-ray spectrum during this stage might be attributed to a beamed component produced in the jet. The characteristic time delay is comparable with the wind travel time to the radius at

which the radio jet becomes optically thin.

5. Future Observational Tests

The existence of collimated relativistic outflows in these two Galactic superluminal sources strongly motivates a search for other examples, particularly in known X-ray transients (HR95). (Observations in the week following X-ray outbursts are particularly relevant in view of the reported behavior in GR0 1655-40.) The two Galactic γ-ray sources, 1E1740.7-2942 and GRS 1758-258 (Mirabel 1994, Chen, Gehrels & Leventhal 1994) show many similarities to the two sources considered above (radio jets, hard X-rays, upper limits on the masses of the stellar companions) as well as some differences (detected γ-rays, correlation between the radio and X-ray fluxes). It is also of interest to re-examine CygX-3 from which Strom et al. (1988) report mildly relativistically moving radio components.

The counterparts of the giant radio lobes by which the extragalactic counterparts of these sources were first recognized (or alternatively of W50) should also be sought. This search should be most profitably carried out at low frequency and as in the extragalactic case the radio source sizes may be very large ($\gtrsim 10'$), depending upon the history and local gas density. As extragalactic observations also emphasize, there are possible strong selection effects and GRS 1915+105, GRO 1655-40 may be just examples of a much larger class, most of which contain jets with larger Lorentz factors and rendered invisible by beaming away from us. These too may be found by wide field, low frequency radio observations of other X-ray transients.

Also drawing upon the extragalactic analogy, a search for ~ 1 GeV γ-rays using EGRET is well-motivated and a successful detection would strengthen the case for $e^+ - e^-$ jets. Conversely, the detection of optical or infrared Doppler-shifted emission lines would strengthen the association with SS433 and argue for an $e - p$ jet.

Given the large inclination derived from the radio source kinematics ($i \sim 84°$, HR95), should a measurement could then be translated into an estimate of the size of the Roche lobe of the companion star. Understanding the size of the orbit and consequently of the accretion disk should also help define the physical conditions in the bipolar wind that we have invoked to account for the jet collimation. Further constraints on the discharge in the wind can come from observing the soft X-rays with ROSAT at energies $\lesssim 1$ keV during the phases when the radio components are being formed. If the outflow is as dense as we propose, then the soft X-rays should be efficiently absorbed. A quite separate bound on the wind density may be derivable by seeking rapid variability in hard X-rays using ASCA during high states. Observation of rapid variability on time scale on timescale t_{var} would imply that any wind be optically thin the Thomson scattering beyond a radius $r \sim ct_{var}$. If, somewhat unexpectedly, the compact object in either source is a neutron star with a measurable spin period, then this test will be much stronger. In addition, we have suggested that the relative strength of the emission lines from this wind should be anti-correlated with the X-ray flux.

However, perhaps the most fundamental understanding as to the nature of these

sources will come from analyzing the kinematics of the radio components to see if there are genuine periodicities in either the timing of the outbursts or, as tentatively supported by the observations of HR95, the component angular velocities projected on the sky. It will be especially interesting to learn if, on these grounds, the Galactic superluminal sources are more affiliated with extragalactic jets or SS433.

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